Hydropower : A Regenerative Energy Source From The Sun

by
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Abstract

The growth in human society and its energy dependence have increased axponentially with time. The prediction of energy use and anternational co-operation to overcome the future need of power supply are the main issues frequently being discussed in the international scientific community. In the lecture, we will try to analyse briefly the possible ways to answer the above mentioned question and deal with more precisely the state-of-art technology of hydropower: a regenerative energy source from the sun. Although considered as environmentally benign, hydropower's future has been the most debated field. Beginning with the fundamentals of hydropower, this lecture focuses to the main issues for the hydropower development, provides information on the present activities of the Institute of Water Resources Management, Hydraulic and rural Engineering in the ecologically oriented hydraulic engineering and deals with some new concepts to develop environmentally friendly hydropower development by combining axperiences in teaching and practice. Moreover, the economic and financing aspects of hydropower have also been addresed for the completeness of the issues.

A. Issues of Hydropower Development

1. Socio-economic and Environmental Issues

Any development projects invariably bring some impact on environment and are also affected from the environment. Thus, hydropower developments, be it big or small, are not exceptional cases. Although hydropower has been considered as an environmental benign means of producing electricity, its hydraulic structures such as dams, weirs, canals frequently change the natural drainage of water. The environmental impact of hydropower are well documented and should not be over emphasised here further. However, the following three examples will suffice the extent of impacts on society and ecology.

Example 1: The Aswan Dam has been considered as an intervention in the ecology of the Nile Valley. The Nile has always had a double fuction in Agyptian agriculture, as it provides both water and

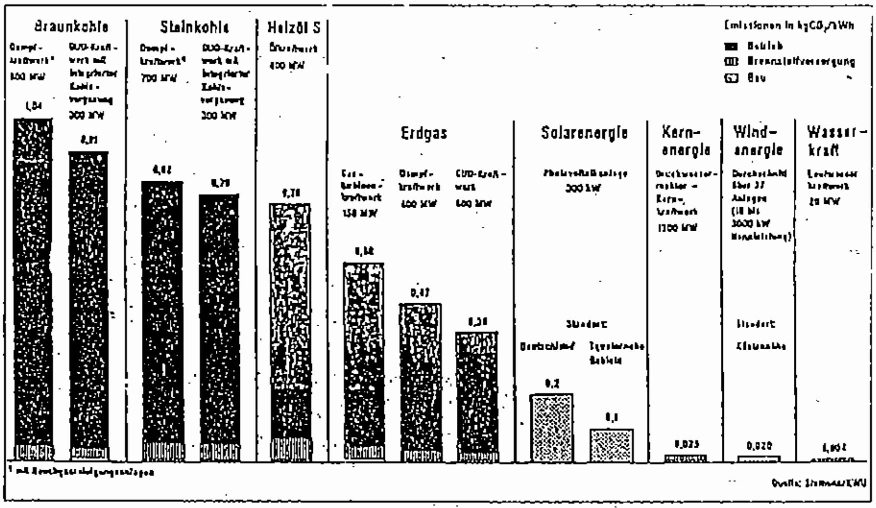

Fig.1. CO_2 Emission from different primary energy sources

fertiliser. However, the long-term impact of the project is now being considered as positive [Mosonyi, 1997]

Example 2: The Sardar Sarovar project in India, which could be the largest dam in the Narmada Basin Plan, involving the construction of 30 large, 135 medium-sized and more than 3.000 small dams on the Narmada River and its tributaries. This project, would displace 200.000 rural, mostly tribal people from their homes. Strong public opposition led to the funding cancellation from the World Bank in 1993. [WB, 1993, online]

Example 3: The size and axtent of impact to the environment of Arun-III hydroelectric project in Nepal was very small as compared to the above two examples mentioned above [Maskey, 1994]. However, the investment was comparably high so that there was doubt on its economic viability. Hence, again the strong public opposition forced the World Bank to withdraw its support from this project in 1995.

Hydropower in general, unlike water supply for irrigation and drinking, does not consume water by itself nor pollute the environment as thermal power station do. It should be emphaissed here that all steam electric generating facilities (Thermal Nuclear) require huge amount of water for steam production and for cooling. They invariably need hydraulic structure to divert water to cooling tower. In addition to the contribution to air pollution (see Fig. 19), the discharge of the heated effluent into the natural water course or reservoirs can cause thermal pollution. Hydropower is, therefore, an :angel among the devils" [Mosonyi, 1997].

It is to be noted from the above mentioned examples that the development of hydropower is not only constrained by socio-economic and environmental criteria but also the financing. We will come to this issue subsequently.

2. Technical Issues

The major areas of ecological concern in hydropower are, perhaps, the pysical blockage of river course upstream and fluctuation of flow downstream and the supersaturated water downstream. This blockage directly affect the aquatic biota (specifically to fish and invertebrates) by disrupting the migration and also downstream agriculture by blocking the flood born silt vital for the nutrition of plants. Realising these isseus, various research projects have been launched for renaturalisation of river stream. For example the hydraulic engineering of river Rhine started in 1828 with little human influence. Then it was continued by engineer Tulla in 1827 with the project to streamline the Rhine for the purpose of river navigation and partly for hydropower generatio. Such modification has changed its natural river regime [IHP/OHP, 1996]. It has threaten the ecological system or river Rhine to such extent that the International Commission for the Protection of River Rhine (ICPR) started an ambitious project called "Salmon 2000" under Rhine Action Plan (RAP) with the aim to restore, protect, preserve and improve the ecologically important reaches and habitat for migratory fishes and aquatic organism in the main stream and tributaries [ICPR, 1995]. This river training programme has also caused deepening of the river by seven metres. Artificial bed load feeding to stabilise the degradation of Rhine river bed is also another example of costly project downstream of Iffezheim [Kuhl, 1993].

To plan an environmentally benign hydropower project, a system of hydropower generation as a whole should be carefully examined to identify the relationship between its components with the surrounding ecology as shown in Fig. 20. Then only proper alternative solutions could be suggested. In the subsequent paragraph, we will make a brief survey of current activities in this area.

First of all, let us split the hydropower generation system into three ecological interest zones (see Fig. 20):

Zone 1. Dam (intake) and upstream inundation zone
Zone 2. Waterways including power house zone
Zone 3. Outlet and downstream water fluctuation zone

In the second zone (see Fig. 21), simple ecological and economic optimal sizing of the waterway system may be sufficient (in case of underground only). With some good environmental management, the problems with open headrace canals in this zone may also be completely solved. However, the first and third zones are most vulnerable in terms of ecology such as upstream inundation, sedimentation, stagnation, change in micro-climate, loss of ecological habitat and etc. Similarly. The downstream faces de-watering, degradation of river stretch and fluctuating water levels and tem-

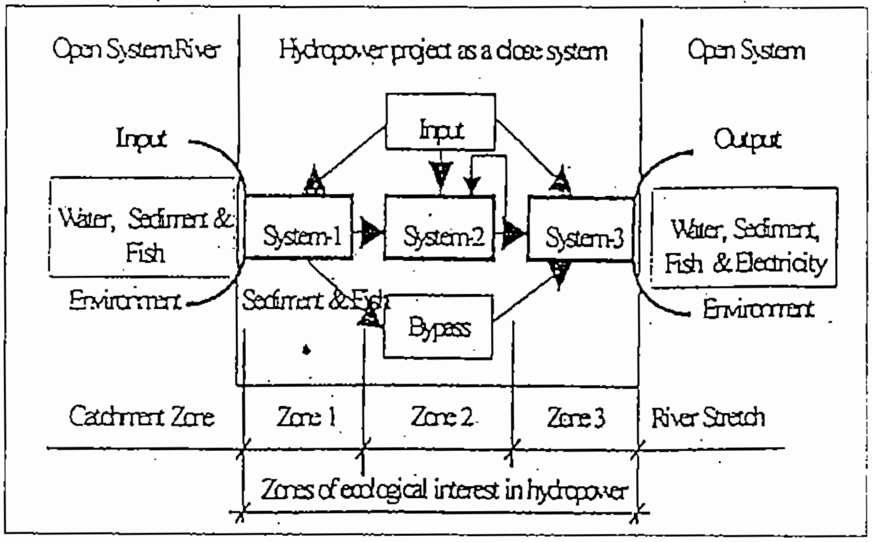

Fig.2. A hydropower ecosystem model

perature which may hamper sensitive aquatic organism [Hansen et al, 1992]. All in all, both zones are detrimental for both fishes and other aquatic habitat as well as it may cause water right problems downstream. Here is the area human intervention is required to establish more complex ecological relationships with the economical factors. Additionally, hydraulic passages for aquatic habitat are not the best and cheapest solution nor the artificial bed loading of the river. A very close study of relationship between morphology and ecology has to be conducted before suggesting any structure.

For example, there are mainly three methods of fish passage which have been used in practice, namely: fish ladders (stair case-like devices), lift and locks (elevator) and trap and truck method. From the evaluation of the hydraulic performance of fish passage structure by US Bureau of Reclamation, USA it was concluded that existing fish passages were not effective and that highly depend on many factors such as gender and spawning condition of fishes. Therefore, a close look to the stream's natural conditions and its behaviour may produce a number of suitable alternatives [Kubitshek and Mefford, 1997]. Thus, alternative solutions to these hydraulic structures upstream and downstream of hydrapower plants should be found for the ecological benign power generation. Among the others such alternatives may be suggested as follow:

1. Design of special river bottom intakes;
2. Design of dam with the provision of aeration of the stratified reservoir level with special arrangement for the by-pass for sediment and migrating fish;
3. Fish friendly hydraulic design of spillways and sluice ways;
4. Design and operation of turbine in its full efficiency to reduce the mortality of the fish passing through turbines;
5. Modification of existing hydraulic structures to allow more generation as well as fish passage;
6. Generating power considering special water management method.

Tyrolean weir, developed in Austria is well known and has been in practice. A modification has been made by the Norwegian engineers to this Tyrolean weir and suggested so called "brook inlet" to avoid intrusion of sediments and air bubbles into the intake without any pond or stilling basin [Hveding, 1992].

However, both intakes are usually aligned across the river and hence posses some restriction to the migration of fishes upstream. The alternative to this may be to align the intake structure along the river bottom which avoids direct blockage of river and provides free access for fishes to migrate (see Fig. 22). Since this type of intake do not store water, it may be suitable specially for small to medium high-head run-of-river hydropower schemes. The authors are planning to investigate such intake structures in near future.

The second alternative is a modification of classical dam design. A dam creates stagnant water pool upstream and completely blocks the flow of sediment and the fish migration. The stagnant water levels are the main cause of poluttion upstream whereas the interruption of sediment and fish migration is one of the main reason of downstream pollution. With special provision of aeration at different stratified levels of the reservoir through selective withdrawal method where temperature and oxygen content are most desirable and a closely investigated bypass system for sediment and fish downstream may be the solution. An example of selective withdrawal may be the lewiston lake temperature-control curtain (see Fig. 23) which was designed to hold back the warm water while colder water released under the curtain through Clear Creek Tunnel into the Sacramento River [Burgi, 1998]. In co-operation with the Tennessee Valley Authority and the U.S. Army Corps of Engineers, the Bureau of Reclamation is developing auto-venting turbine technology that use aeration of power plant releases. This alternative is suitable for storage type hydropower schemes.

Water dissipated downstream of spillway and sluice way usually over saturated with air which are not good for fish [Hveding, 1992]. To address this issue, spillways at some hydro dams have been modified either taking advantages of surface oriented behavioural pattern to bypass fish via instalation of prototype overflow weirs or with flow deflectors to reduce total dissolved gas levels in the river. This experiment, conducted on the Columbia River, has revealed that not all spillway modification are 100% fish friendly. It was found that depth of the tainter gate opening, amount of gate opening, discharge volume, obstruction in flow path (e.g., dentated, and end walls), excessive turbulence, presence of boulders, etc. may affect the fish survival [Mathur et al., 1997].

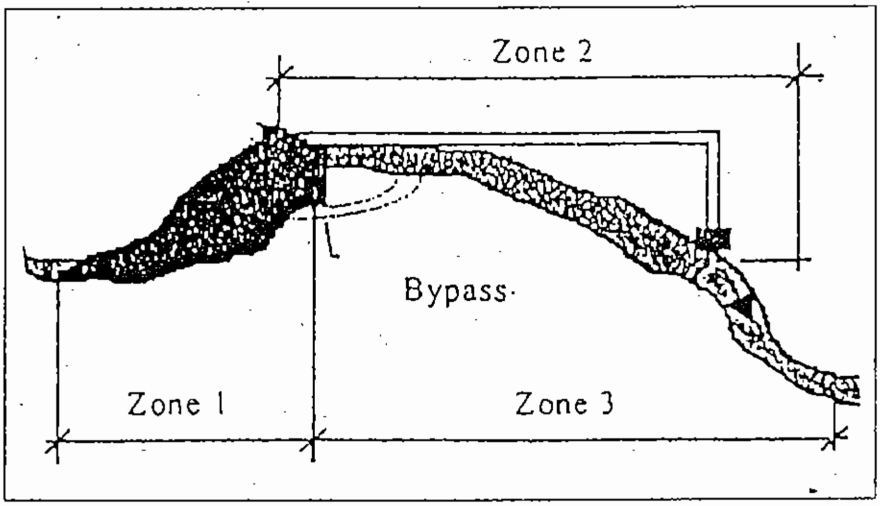

Fig.3. Ecologically sensitive zone of a hydropower system

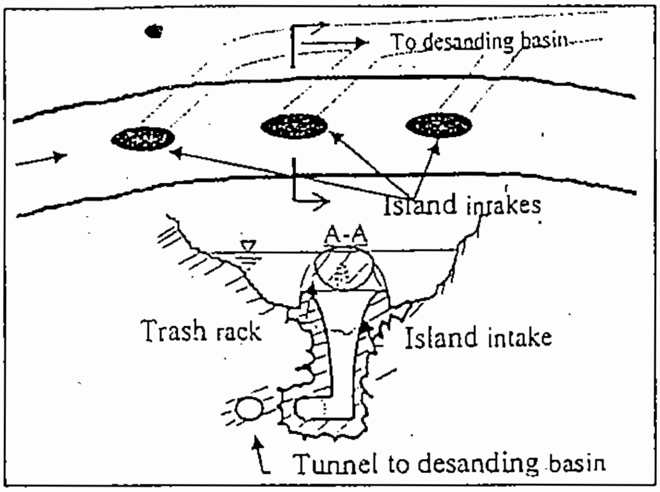

Fig.4. Shcemtic diagram of Island type intake located along the river course

Similarly, various physical and numerical models have been used to predict the trajectories of virtual fish through complex turbine geometry. Despite its peliminary stage of development, such modelling may be useful for assessing the fish friendliness of existing and propose turbine design [Sotiropoulos and Ventikos, 1997]. It has also been concluded that at the maximum efficiency of runner the mortality of fish is minimum.

Modification of existeng dams and weirs used for irrigation and water supply to allow the power generation may be one of the attractive proposition to generate ênergy as well as conserving the nature by avoiding its further expantion. Similarly, modification of such existing hydraulic structures for fish movement is being implemented in various sites (e.g., establishment of fish ladder at Iffezheim power station).

Authors are planning to investigate alternatives for the design of a special intake structure with movable damming parts like a barrage. With special water management, this will allow the intake to take water when the load demand is high and let the river at its natural condition all other time (with the philosophy of "let the river be river and take the water if you need the power"). The main idea behind it is to avoid the direct blockage of river by structures. The headwork consists of barrage, the inverted level of which, coincides with the river original bed and the intake is located in the pears. The intake may be termed as the "pier-hear" intake (see Fig. 6).

During the power peak season, the water is taken to the tunnel by blocking the river. All other time, the plant will operate in run-of-river regime and it lets water flow freely in the river. Care should be taken not to block the river during the migration season of fishes. In this case, it is very important to compare the frequencies of fish migration and flood in a particular river basin with respect to power demand from the system of that region. Since the head is created only by running tunnel downstream, this type of intake is suitable only for high-head hydropower with run-of-river schemes. In this case the operation of hydropower is highly stochastic in nature and it requires special attention in decision making for optimal power generation [Fahlbusch, 1983].

3. Issues of Planning and Appraisal Techniques

Hydropower is a multidisciplinary subject and its planning demands wide range of knowledge of technology, economics and environment. A multidisciplinary team of experts in hydrology, survey, ecology, design and economy should be formed and involved right from the beginning of the project development cycle.

The hydropower Development cycle begins with the pre-construction phase involving different stages of study such as reconnaissance study, prefeasibility study, and feasibility study producing document for loan application and appraisal by financ-ing institution. After this, a definite plan study is carried out which eventually produces the design report and the hydropower development enters the construction phase which involves the tendering, contracting and construction activities, Subsequently, the hydropower planning process enters the phase of operation and maintenance where periodical monitoring and auditing are necessary to gain feedback for next hydropower planning cycle. Fig. 7 explains the hydropower development flow where at every definite point, a concrete decision has to be made by the owner.

For the plan formulation of the hydropower project and subsequent project appraisal the following main physical data input are necessary. These are general data on socio-economy, power market (de-mand), tariffs, en-vironment, hydro-logy, topography, geology (soils, mate-rials), infrastructures. Fig. 26.

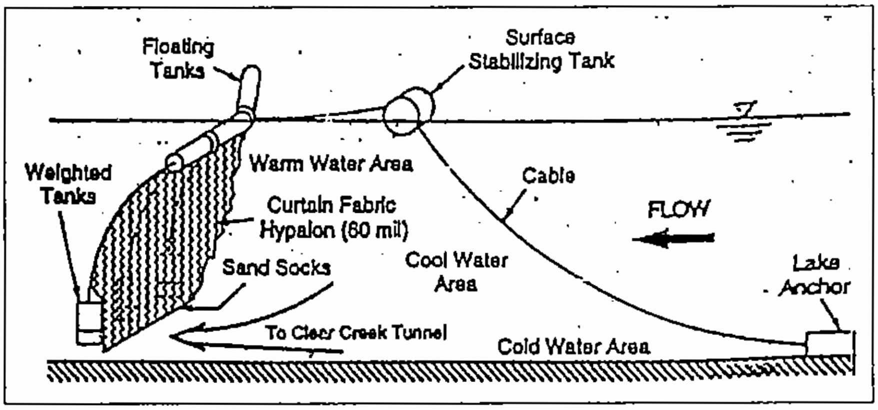

Fig.5. A temperature control curtain for selective withdrawal (Source: Burgi,1998)

Shows the basic studies taken for the formulation of hydropower instalation.

Finally, the cost estimates and revenue determination are the basic inputs for the project appraisal. During the preparation of the project report for financing, two basic pre-conditions must be fulfilled:

- The economic analysis must be transparent
- The solutions to be compared must be realistic and feasible

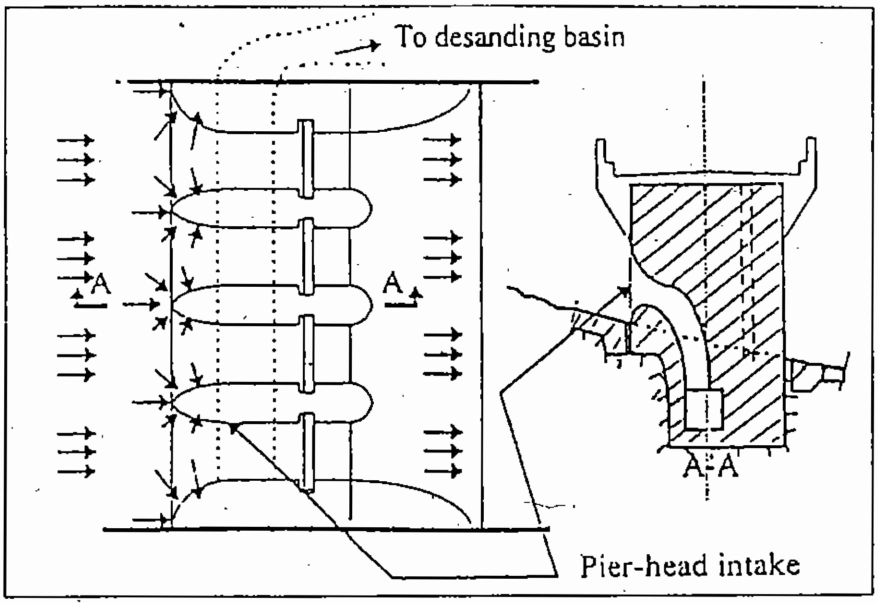

Fig.6. Shcemtic diagram of Pier head inteke structure

Cost estimates for hydro schemes are specific for each project and each site. General cost data are not relevant although they may give an indication of the ranges within which component costs can be expected to lie and of the cost trends that might be expèrienced. They may also provide guidelines for project optimisation. Based on various hydropower projects all over the world, the following cost trends can be generalised [Goldsmith, 1993]:

- The pre-investment expenditure of the scheme falls with increasing capacity;
- Specific costs of hydro schemes (per kW installed) decrease with increasing capacity and increasing head (see Fig. 9)
- Isolated schemes are more expensive than gird connected and easily accessible projects near existing power markets;
- Use of local materials, labour and equipment reduces specific costs but the advantage becomes less marked with larger installed capacities;
- Simple technologies can lead to cheaper construction but they become more difficult to apply in larger schemes;
- Investment requirements increase with the number of units installed in the station- with the total installed capacity remains unchanged- but this disadvantage is counteracted by the better availability of the power plant;
- For small schemes, below about 5 MW, the electromechanical component is responsible for the larges proportion of the total costs;
- The most expensive item of the civil works is usually the headrace and the pressure conduit system and this requires therefore the greatest care in design optimisation.

The cost items in a comparison of the generating costs for hydroelectric vs. thermal-electric power, criteria other than the investment cost per kW output must be considered (e.g., long service period and less operating costs etc.). Although in the Federal Republic of Germany, for example, the investment in a pump-storage-reservoir power plant costs 600 to 700 DM/kW. While a gas0turbine plant costs only 350 DM/kW, the generating costs per kW are comparable.

Furthermore, pump-reservoir plants are used to supply power only during the periods of peak demand, thus allowing a more economical use of large thermal plants (especially nuclear plants) which are most efficient when operating at full capacity, and also, because of their low environmental impact, the expenditur-

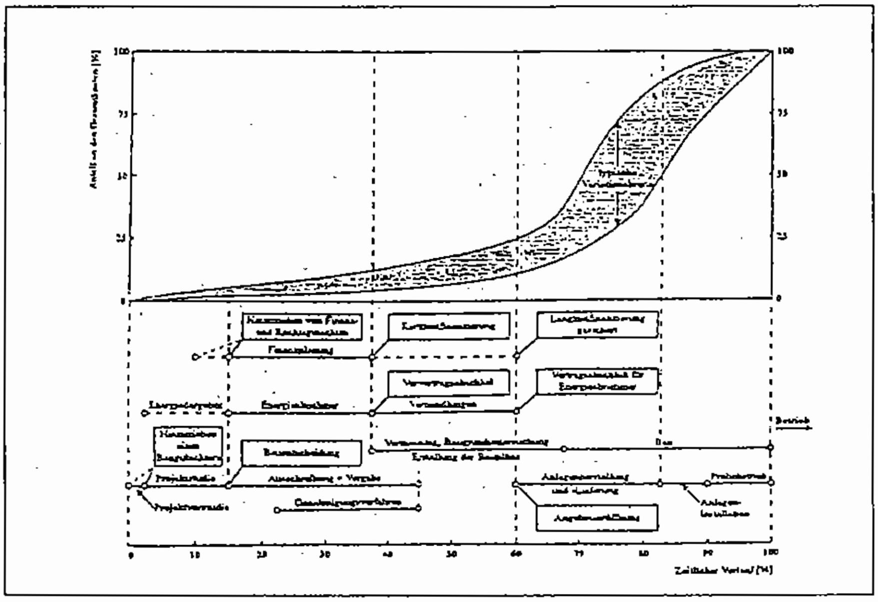

Fig.7. Hydropower Development flow chart

es to preserve environmental quality are very low for hydroelectric plants. Many economically attractive projects may not be feasible financially. Therefore, proponents have to be clear about the project before implementation. Similarly, the environmental and socio-economic criteria may hinder the progress of hydropower development. It is, therefore, required that the possible steps that are relevant to address these issues, must be included in the project planning cycle as shown in Fig. 28: Economic indicators of hydropower plants are:

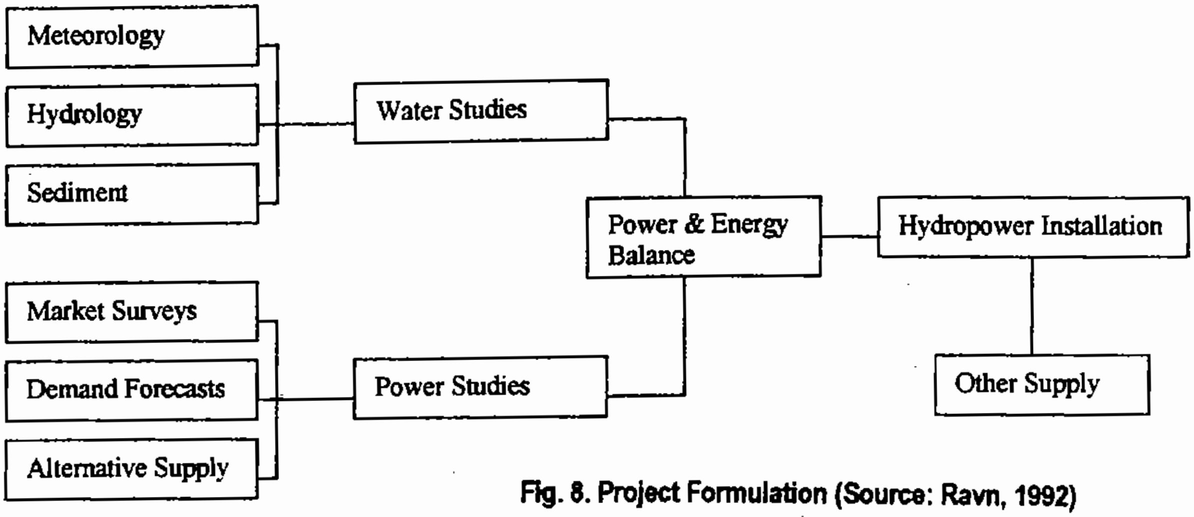

Fig. 8. Project Formulation (Source: Ravn, 1992)

- Cost-benefit ratio
- Net present value
- Internal Rate of Return

4. Issues of Public and Private Financing in Hydro-power

Past experien-ces on classical hydropower planning have shown enormous problems in terms of financing and managing the project. On one hand, due to the strong competition on scarcely available public fund, the development of hydropower sector is not geareng up. On the other hand, the private sector is not attracted to venture because the hydropower sector is characteristically capital intensive with long gestation period.

Therefore, many governments throughout the world, especially in developing countries are now seeking to attract private financing in the hydropower development [IFC, 1995]. Privatisation of public properties in industrialised nation as compared to developing countries are not big issues. The private sectors require guarantees on safety and profitability on their investments more than the public sectors (see Fig. 29).

Unlike the public sector, the private sector is profit oriented and may disregard the social importance of hydropower. One the major differences between public sector and private sector management of hydroelectric power is the system reliability consideration [Rashid, 1993]. Private sectors are concern with cost minimisation to maximise the return. Capacity addition are essential to increase reliability of the power system, but it will also raise the cost of investment. Private sector will not add capacity in such cases even when demand is rising rapidly. Even if there is a good policy to attract the IPP in the power sector they may opt either for a thermal generation, or go for the run-off-the river project which is less suitable for system reliability.

With this fact, a public sector least cost solution may result in a optimal mix which doaes not coincide with the least cost solution determined by the private investor. The public sector needs to determine the role of hydroelectric development in the power mix and should lead to a rational exploitation of the available

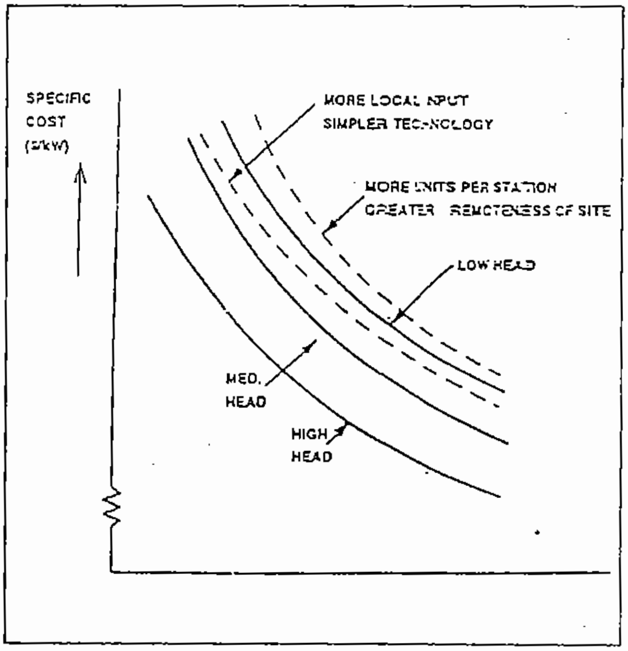

Fig.9. Cost/size relationships(Source: Gold smitht,1992)

resources keeping in view of short and long term requirements of the nation.

Among the other important issues to be addressed in the development of hydropower with the involvement of IPP are the issues of implementation of projects which have been studied to feasibility level by public sector where IPP are not allowed to alter the project optimisation; issues of risk sharing where 'public-private partnership' may be one solution for the economic development of hydropower; issues of multi-purpose development of water resources where the development of hydropower should be rationalised; issues of downstream water use where Trans-boundary problem may hinder its smooth development; issues of water pricing where the question of social unrest may arise, and so on [Maskey, 1997]. Future hydropower planning should be evaluated on basis of its sustainability in long term i.e. it should be economical, environmentally benign and techno-financially manageable. Therefore, a new approach to the solution of hydropower planning and management is also required to be explored for a rational utilisation of water resources.

B. Future Hydropower and Role of IWK

It is evident that hydropower plays a key role at present and future in supling the energy and power to the world. Given the fact that hydropower is not truly benign to environment in absence of good management, it is necessary to take seriously the following issues for future hydropower development:

- Technological improvement and innovation to take hydropower components more environmentally friendly;
- Maximum utilisation of already existing hydropower plants and its component through renovation, refurbishing and capacity addition;
- Development of hybrid technology to store water using solar energy;
- Integration of environmental economics in the project cycle so that tangible and intangible value could be included in the economic analysis;
- Research and development of the methodology for project financing to boost hydropower through private sectors;
- International co-operation in technical as well as financial aspects;
- Monitoring of project implementation with respect economy and environment;
- Continued education and training of new generation in hydropower management.

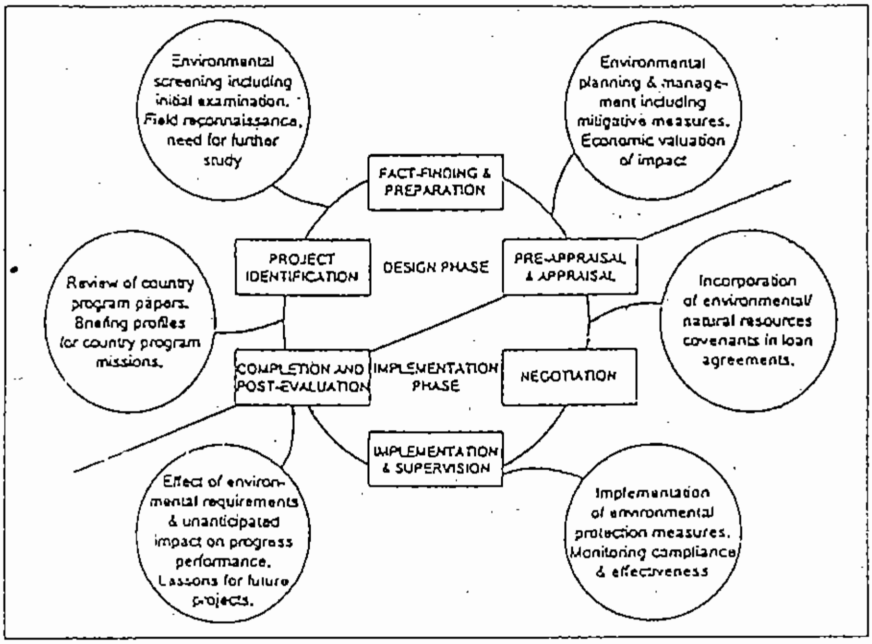

Fig.10. Project planning cycle including the environmental clearance process (Dixon et.l., 1988

The institute for Water Resources Management, Hydraulic and Rural Engineering (IWK) is one of the few institutions in Germany to realise the trend of future hydropower by concentrating the technological, ecological, economical and managerial tasks in energy research as shown in Fig. 30.

IWK is actively involved in developing the ecologically friendly hydraulic structures through integration of research and practice [Nestmann, 1998]. IWK is playing vital role in close collaboration with Germany Technical Co-operation (GTZ) and Water and Power Development Authority of Pakistan (WAPDA) for the development of training materials on hydraulics and hydropower at several Universities in Pakistan [Nestmann and Palt, 1996, 1998]. Similarly, there has been an extended work to establish an international co-operation with Russia on the Volga project. IWK also has a future plan to support Indonesia and Nepal in the field of education in hydraulics and hydropower by providing its vast expertise.

Present activities of the IWK comprise mainly the following area:

- Physical and numerical model study of fluvial morphodynamics,
- Numerical modelling of regulation and operation of hydraulic structures,
- Interdisciplinary work such as sediment transport, soil erosion from land and river,
- Artificial bed loading,
- Aspects of biotoc and abiotic relationship of river hydraulics,
- Physical and numerical modelling of hydropower plants,
- Establishment of hydropower laboratory and demonstration stands,
- Developing and testing of training manual in hydropower for Pakistan,
- Research and development of river restoration projects.

C. Conclusion

Hydropower, the renewable source of solar energy, is a proved technology

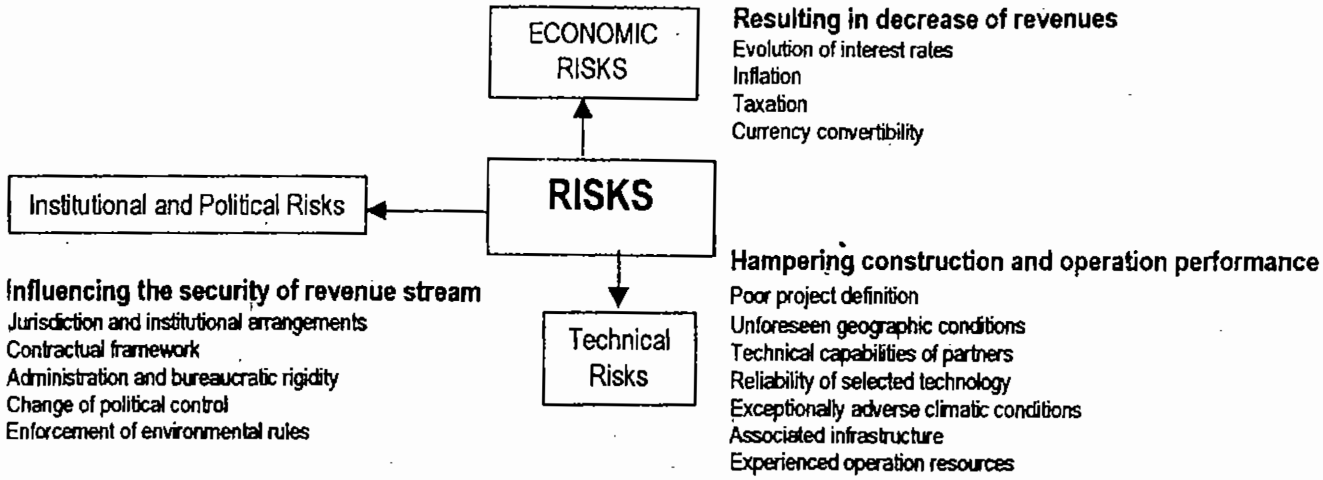

Fig. 11. Families of major risks in Private Power Projects (Gailard, 1997)

and its impact on environment is of local nature and relatively well known for which possible remedial measures have also been suggested in many literature [Jacobsen, 1984; Hansen et al., 1992]. If planed and implemented properly, it may support the development of other infrastructure that are vital for economy and protection of the environment.

To fulfill the energy gap, many technologies using renewable and non-renewable sources of energy have been suggested and developed till present and no doubt the future will see many more. However, the robustness of the hydropower technology and its flexibility to meet the energy demand have been tested for century. What is required is the research and development of new ecologically friendly hydraulic structures through renovation or modification of existing dams and weir to meet the stringent environmental criteria. Moreover, quantification of intangibles and monitoring of the project implementation are other important aspects to consider for a proper ydropower management.

The LDC have vast potential for hydropower development but lack technology and financing. Whereas, the MDC have better technology and capable to finance. Only through international co-operation, we may solve the global energy crisis by developing the renewable sources of energy, particularly, the hydropower in LDC. The international co-operation to develop curricula for the universities particularly applicable to the local conditions are vital for the sustainability of local capability in the development of hydraulic and hydropower engineering. In this respect, the role of German government, in general, and IWK, in particular, is praiseworthy.

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2) *R.K. Maskey, M.Sc. in Civil Engineering, Ph.D. student at the above mentioned institute, Karlsruhe. Prepared for the 11th International Solar Forum 1998 26th - 30th Juli 1998, Köln.*

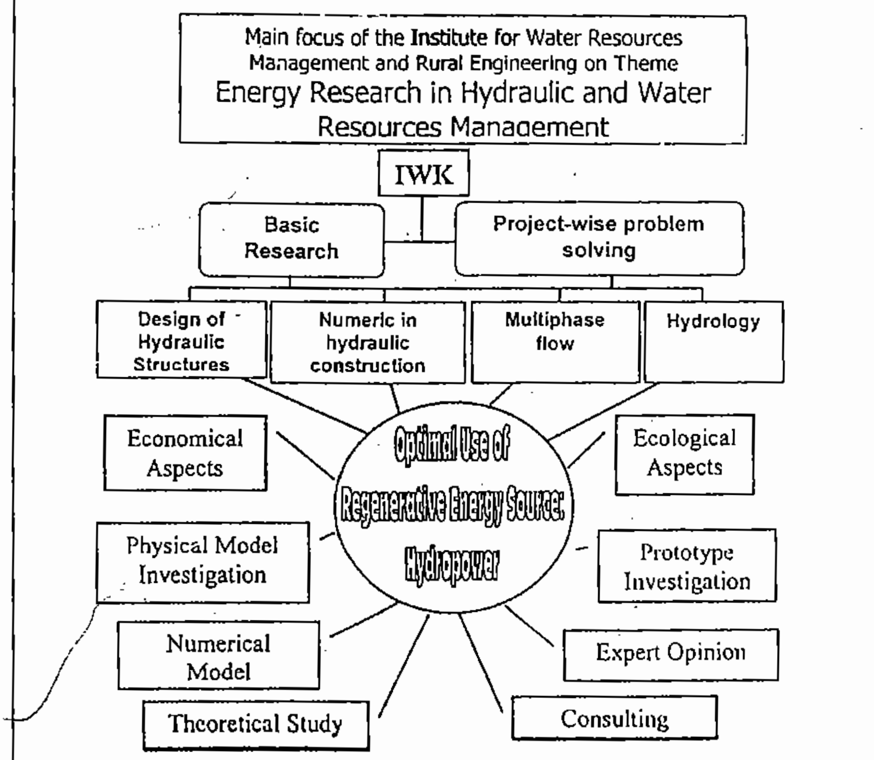

Fig.12. Energy reseaersh plan of IWK (Source: Nestmann, 1998)